Field observations of the bidirectional reflectance characteristics of lake ice

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Introduction

The albedo of ice is an essential parameter related to the cold region's research of the energy exchange between water and atmosphere, which can be retrieved from remote sensing data. However, reflectivity data are not equal to the ice actual albedo because satellites have a limited field of view at a specific wavelength and observing angles. Anisotropy corrections are also needed according to the underlying surface properties. As ice has strong forward scattering, and its optical properties are sensitive to its physical parameters. So there are many differences in reflectance between different types of ice in different observed angles, which result in large uncertainties in albedo retrieval. To deal with these difficulties, during the winter in Feb 2019, field observations of Wuliangsuhai lake, Inner Mongolia were obtained. Spectral measurements of albedo, bidirectional reflectance distribution function (BRDF) were made for the five following ice types: (i) ice with nonuniform bubbles under the overcast skies; (ii) ice loading much sand; (iii) ice with big bubbles; (iv) ice with dense small bubbles, and (v) melting ice.

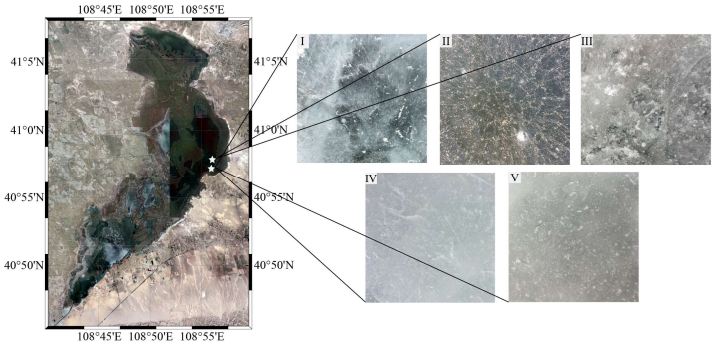

Figure 1 Experiment site in Wuliangsuhai lake (Base map on the left is a satellite imagery from Google map)

The experimental setup for BRDF

The definition of BRDF is:

$$f(\theta_i,\varphi_i,\theta_r,\varphi_r,\lambda)=\frac{dL_r(\theta_i,\varphi_i,\theta_r,\varphi_r,\lambda)}{dE_i}$$

where θi and φi represent the zenith and azimuth of the incident light respectively. And θr and φr represent the zenith and azimuth of reflected light. Lr is the radiance of reflected light. Ei is the irradiance of incidence light. λ represents the wavelength. According to the definition of BRDF, the experiment device is designed as shown in Figure 2. Lr with different azimuth and zenith angles can be got by this device. And BRDF equals to the ratio of Lr and corresponding downwelling irradiance.

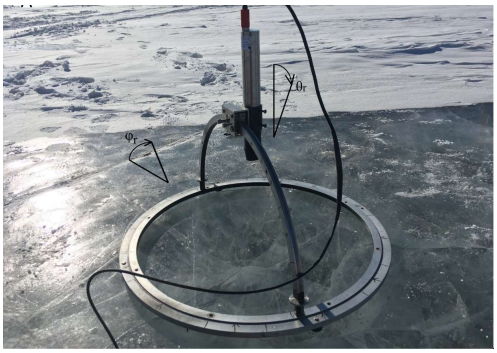

Figure 2 Experimental setup for BRDF

Results

To cope with the angle limitation of remote sensing data, it is necessary to understand the spatial distribution characteristics of BRDF. The following figures show the responses of BRDF to zenith (in the principal plane) and azimuth.

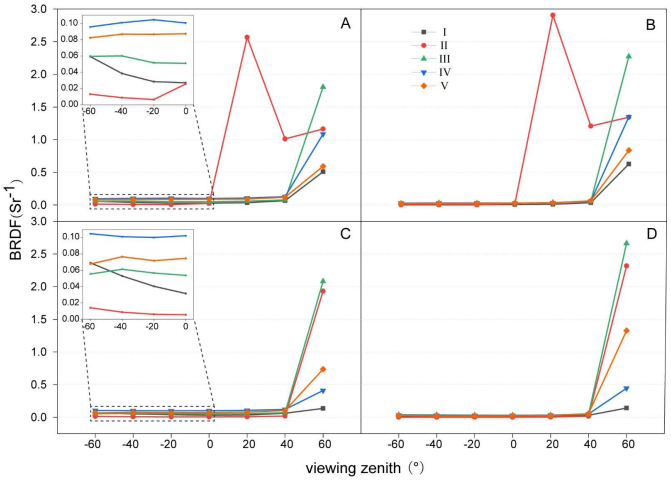

Figure 3 BRDF of principal plane (A,C:λ=450nm; B,D:λ=850nm; A,B:θi=56.5-58.6°; C,D:θi=62.1-65.2°)

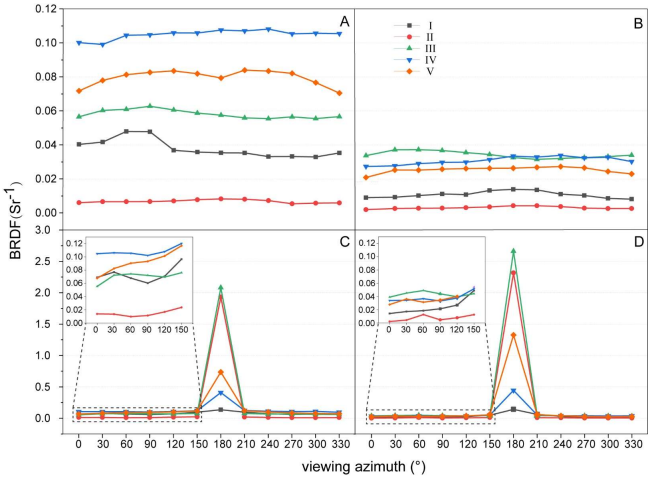

Figure 4 BRDF as a function of azimuth（A,C:λ=450nm; B,D:λ=850nm; A,B:θr=20°; C,D:θr=60°）

Conclusion

In this paper, the optical properties of several typical lake ices in Wuliangsuhai Lake in winter are investigated to study the bidirectional reflection characteristics of ice. The scattered light of ice is composed of two parts, the volume scattering in the ice and the surface reflection from the ice surface. The results show that volume scatter will be slightly affected by the uniformity of ice properties in the shortwave band, and it is not sensitive to the zenith angle and azimuth angle in the longwave band. The surface reflection will form a reflection peak point in the forward scattering direction, and the zenith angle position of the peak is affected by the ice surface. According to the conclusions above, the observed angle limitations of remote sensing data can be avoided when calculating the albedo according to reflectivity.

Acknowledgement

This work was supported by National Key R&D Program of China (2018YFA060901); National Natural Science Foundation of China (41876213, 51979024)